

MONITOR FOR STATUS EPILEPTICUS SEIZURES

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ABSTRACT

This paper describes the sensor technology and associated electronics of a monitor designed to detect the onset of a seizure disorder called *status epilepticus*. It is a condition that affects approximately 3-5 percent of those individuals suffering from epilepsy. This form of epilepsy does not follow the typical cycle of start-peak-end. The convulsions continue until medically interrupted and are life threatening. The mortality rate is high without prompt medical treatment at a suitable facility. The paper describes the details of a monitor design that provides an inexpensive solution to the needs of those responsible for the care of individuals afflicted with this disorder. The monitor has been designed as a cooperative research and development effort involving the United States Army Armament Research, Development, and Engineering Center's Benet Laboratories (Benet) and the Cerebral Palsy Center for the Disabled (Center), in association with the Department of Neurology at Albany Medical College (AMC). Benet has delivered a working prototype of the device for field testing, in collaboration with Albany Medical College. The Center has identified several children in need of special monitoring and has agreed to pursue commercialization of the device.

EPILEPSY

Epilepsy is a disorder of the brain characterized by recurring seizures, in which there are uncontrolled electrical discharges of brain cells [1]. Epilepsy may arise from a very small area of damaged brain tissue, or from the entire brain. There may be no apparent brain damage, or damage limited to an area so small it cannot be detected. Therefore, in nearly one-half the cases, the cause of epilepsy is not known.

There are several types of seizures associated with epilepsy, the most common of which are generalized tonic-clonic (grand mal), absence, (petit mal), complex partial (psychomotor), and elementary partial (focal motor). Each seizure type can be characterized by various symptoms. However, the seizures are generally not life threatening, lasting at most up to three minutes. The exception is *status epilepticus*, also called continuous seizure state. This is the occurrence of repetitive or continuous seizures and affects approximately 3-5 percent of those individuals suffering from epilepsy. It can exist with all types of seizures and may result in irreversible brain damage or death without prompt medical treatment.

THE PROBLEM

We were requested to develop a device that could detect the onset of *status epilepticus* in a child during sleeping hours. The seizures begin as complex partial and progress to generalized tonic-clonic. The early stages of the seizures are characterized by a loss of consciousness during which there are minor, barely perceptible tremors. The monitor was to supplement the ineffectual periodic observation of the child by the parents.

A SOLUTION

A motion sensor has been designed with nearly omnidirectional response that can detect the 'hard shiver' activity characteristic of complex partial seizures. The sensor is small and inexpensive to produce since it detects without measuring. It is less responsive to casual and temporary body motion (rolling over, etc.) than to the activity of the tremors. Electronics provide further filtering to the sensor

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signals to ensure consistent results at all orientations. Quasi-continuous activity for a finite period of time is used as an indication of seizure activity. Although the monitor is designed to ignore occasional movements not indicative of a seizure, false alarms will occur. Therefore, sensitivity adjustments have been included. If the alarm criterion is satisfied, a radio frequency signal is transmitted every 30 seconds to a compatible receiver that activates/deactivates any desired alarm mechanism.

The sensor, electronics, and commercially available, FCC compliant (HBW74A) transmitter are packaged in a small, lightweight, plastic housing that is easily attached to a child (figures 1a and 1b). An on/off switch is recessed in the side. A 120V, 60hz, alarm mechanism (light, radio, etc.) is plugged into a compatible receiver 'trained' to the transmitter signal. Although a number of devices may be used simultaneously, total power requirements should not exceed 600 Watts. The receiver is then plugged into a wall outlet within 20 feet of the monitor. The transmitter/receiver should be tested (manual button at the top of the monitor) to ensure the signal is properly received. The monitor is then attached to the child and powered on.

TECHNICAL DETAILS

The Sensor

The sensing element is an intermittent switch consisting of a small, electrically conductive sphere which is able to move within the confines of a small hollow cylinder with closed ends (figure 2). The sphere is stainless steel and has been chemically treated (Marble's Reagent) to enhance surface roughness. The wall of the cylinder is conductive as are the end plates each of which are separated from the cylinder wall by an insulator. The end plates are electrically connected and form one pole of the switch. The cylinder wall is the other pole. When the sphere is in contact with either of the end plates and the cylinder wall, the switch is mechanically closed. However, depending on the presence of oxides and/or surface roughness, the contact resistance may be quite high and the switch may or may not be electrically closed. The important feature is that even small motions of the switch cause the ball to roll. The mechanically closed position (sphere in contact with the cylindrical surface B and one of the end caps A) is the only stable position of the sphere, so most rolling occurs in this position. As the sphere rolls, electrical contact with the wall is intermittent due to the variations in contact resistance. The surfaces have been tapered to improve the probability of a weighted contact. Figure 3 shows typical sensor response characteristic of the complex partial seizures to be detected. No attempt has been made to optimize the taper or utilize curved surfaces since the design of figure 2 has proved to be satisfactory.

The Electronics

A schematic of the monitor electronics is given in figure 4. The electronics are based on an 8-bit RISC CMOS EPROM microcontroller [2]. The microcontroller is designed to operate between 3 and 6 volts from DC to 20Mhz. High speed is not required so the microcontroller operates at a low voltage (4 VDC) and low clock speed (75khz) to conserve power. Power is derived from the 12 volt power source of the transmitter. A Maxim MAX874 low-dropout, precision voltage reference is utilized to supply the 4 volts to our circuitry. This voltage reference was selected because of its low quiescent current (10 μ A) and dropout (200mV) voltage. The MAX874 sources or sinks up to 400 μ A at supply voltages ranging from 4.3 VDC to 20 VDC. Nominal current draw of the circuit (including 12 volt passive transmitter operation) is 25 μ A when the processor is in a quiescent mode and 85 μ A during oscillation. When activated, the transmitter draws 5 mA. Although there are many influencing factors, the useful battery life of an Eveready A23 12 volt alkaline battery or equivalent is estimated to be 2 months if the device is used every night for 9 hours.

With the exception of the 20 pF crystal tank capacitors, all capacitors (1000 pF) are for decoupling. The 262k feedback resistor in the oscillator circuit is required to prevent over driving the crystal. The 100k resistor eliminates spurious oscillations and reduces standby current drain. Battery voltage is dropped by a voltage divider network and periodically monitored by an on-chip A/D converter at pin 17. Pull-down resistors at terminals 9-12 define the default logic settings for the jumpers. The

jumpers may be used to disable the battery test (J1), increase the monitor sensitivity (J2), decrease the sensitivity (J3), and enable debug mode for diagnostics (J4). The diagnostic information is transmitted through a serial link at output port 2. Data is transmitted at 150 baud (6.7 msec pulses) with one start bit, 8 data bits, and 2 stop bits. A 1488 or similar protocol converter must be used to ensure RS232 compatibility (figure 5a). Information on jumper configurations, battery voltage, and pulse count are provided (figure 5b). A 9155 VMOS power FET driven by microcontroller output port 1 simultaneously switches the transmitter and alarm LED. The sensor is monitored at terminal 13.

450 lines of microcontroller code define the system operation. Upon power-up, interrupts are all disabled and the input/output port definitions established. The A/D converter characteristics are defined, but the converter is disabled to conserve power. The jumpers are monitored and the system initialized after which the processor goes into a power saving quiescent mode. Although a watchdog timer is available that is capable of resetting the system every 2.5 seconds, it was disabled to conserve power. Excessive current draw occurs while the processor forces the crystal tank circuit into oscillation at lower frequencies. Approximately 500 msec are required to achieve stable oscillation, with a 230 μ A peak current draw. In fact, contrary to the claims of the manufacturer, reliable start-up at 32 khz was unattainable, particularly with the SOIC (surface mount) package. While in the quiescent mode, the oscillator is disabled until it receives an interrupt indicating a signal change from the sensor. At this point a real time clock/counter (RTCC) is enabled and the interrupt vectors redefined to mask all interrupts except those from the internal clock/counter. Signal transitions are measured at 100 msec intervals to minimize sensitivity variations resulting from different sensor orientations. After approximately 35 seconds of multiple RTCC interrupts, the processor compares the acquired data with that of a threshold value defined by the jumper configurations and measures the battery voltage. If the activity or battery voltage do not warrant an alarm, the processor returns to the power saving mode. If either the battery voltage is too low (9 volts) or the activity exceeds the threshold, the processor toggles the receiver with a 500 msec pulse through the VMOS power transistor. For the transmitter/receiver control modules selected, pulse widths under 400 msec were unreliable and those in excess of 700 msec could cycle the receiver two times (i.e. no noticeable effect). The signal is retransmitted every 30 seconds until reset, which turn the alarm on and off periodically. This ensures the device attached to the receiver will be activated in the event an alarm condition occurs before the receiver is set. This also reduces the risk of an alarm signal being completely masked. The LED in series with the transmitter is used as a local alarm by transmitting 25 msec bursts (3 percent duty cycle) between the 500 msec. pulses. This is enough to flash the LED but not activate the receiver.

RESULTS

The monitor has only recently been turned over to the Center for the Disabled for preliminary testing. It is a replacement for an earlier design that provided much needed data. Many of the enhancements were made based on recommendations by the parents of the afflicted child. We believe the new design corrects all of deficiencies of the earlier model, but anticipate the need for refinements as the testing proceeds.

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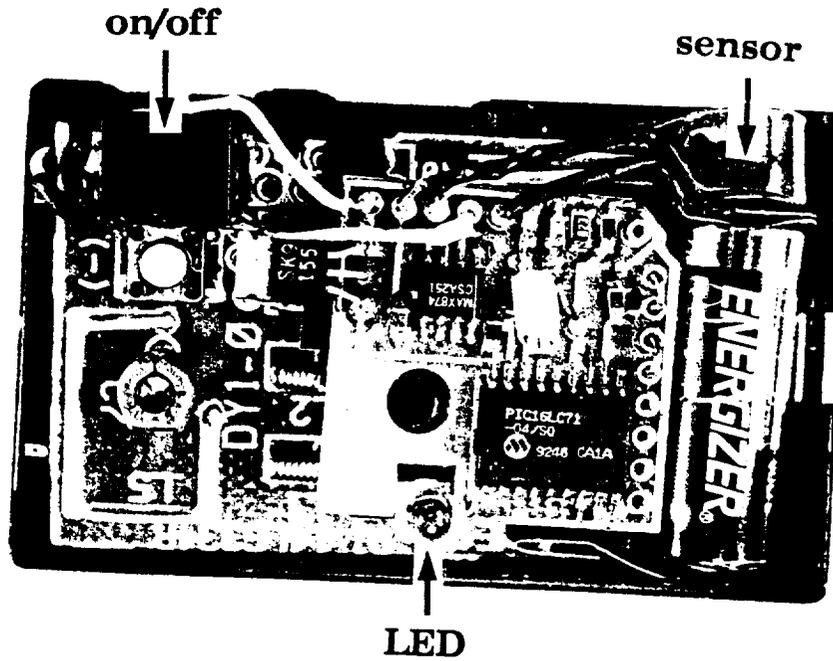


Figure 1a. Monitor Electronics and Sensor



Figure 1b. Monitor (actual size)

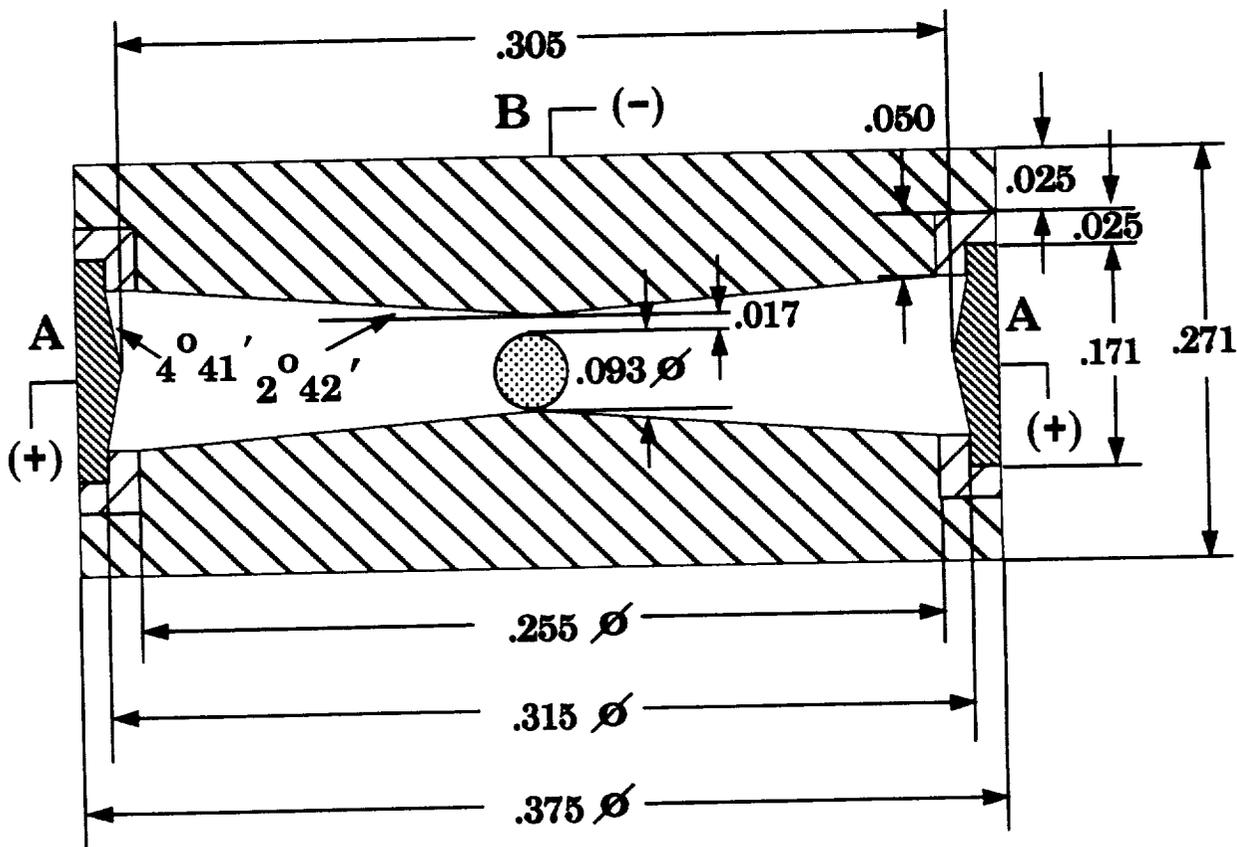


Figure 2. Motion Sensor

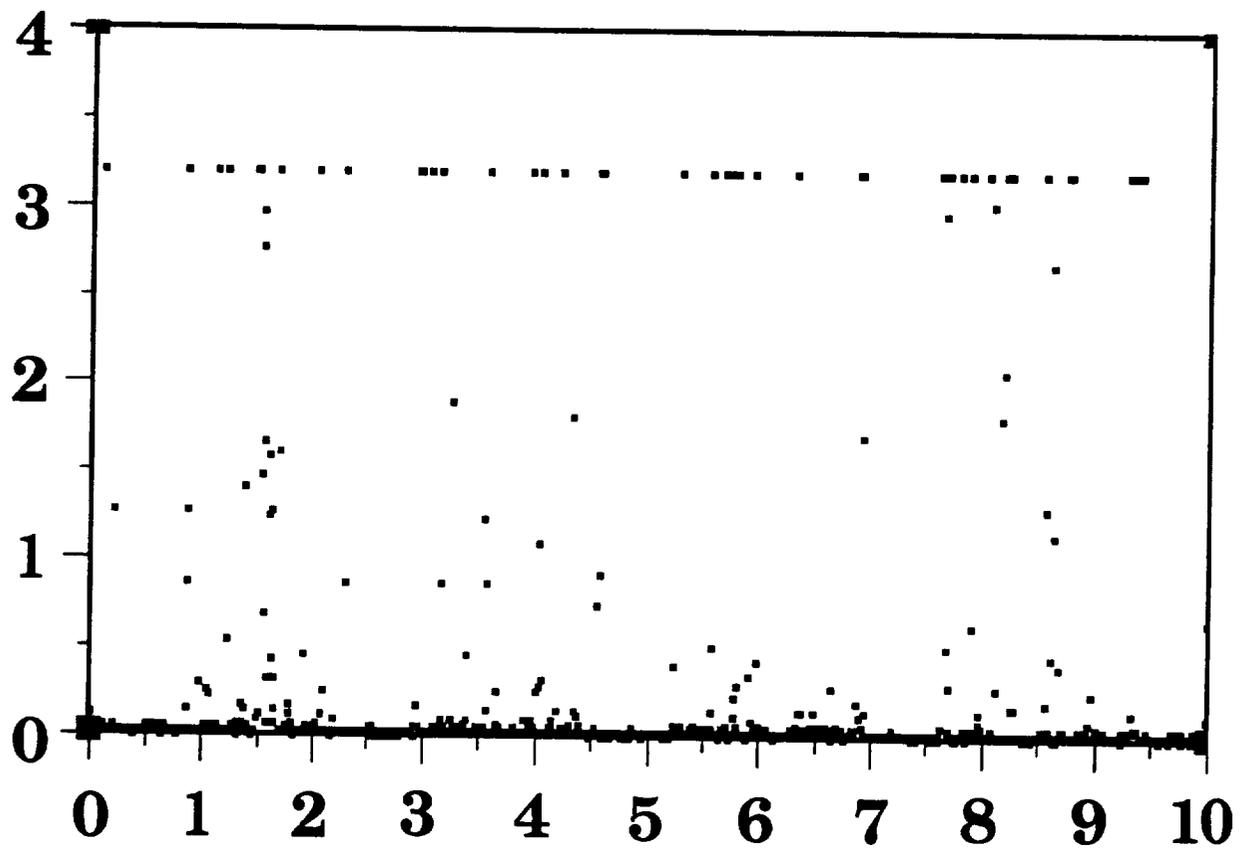


Figure 3. Sensor Response
(Volts vs. 100 msec)

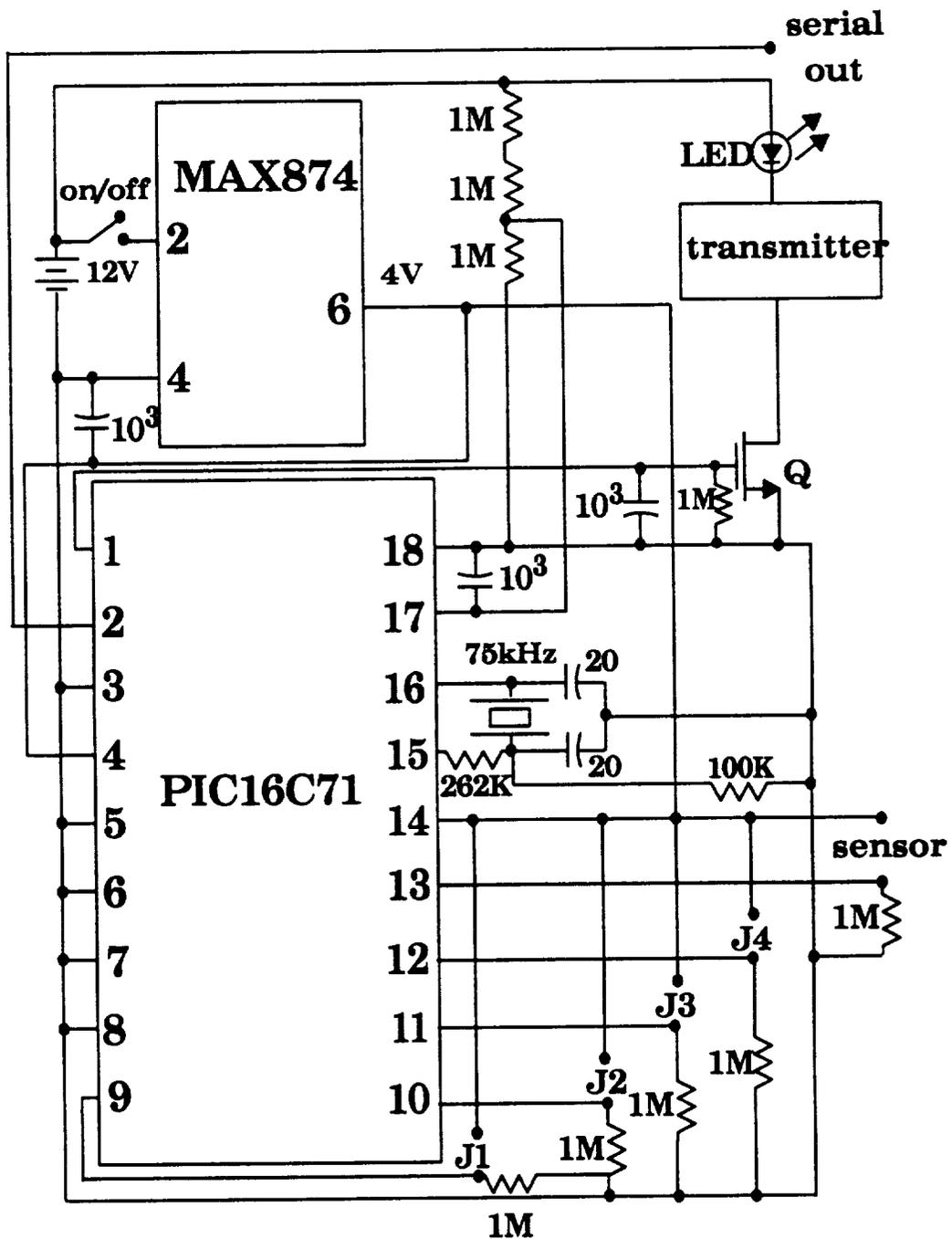


Figure 4. Monitor Schematics

all resistance values in ohms
 all capacitance values in pF
 unless otherwise specified
 Q1 = 9155 VMOS power FET

jumper settings
 J1 = battery test enable
 J2 = debug enable
 J3 = increase sensitivity
 J4 = decrease sensitivity

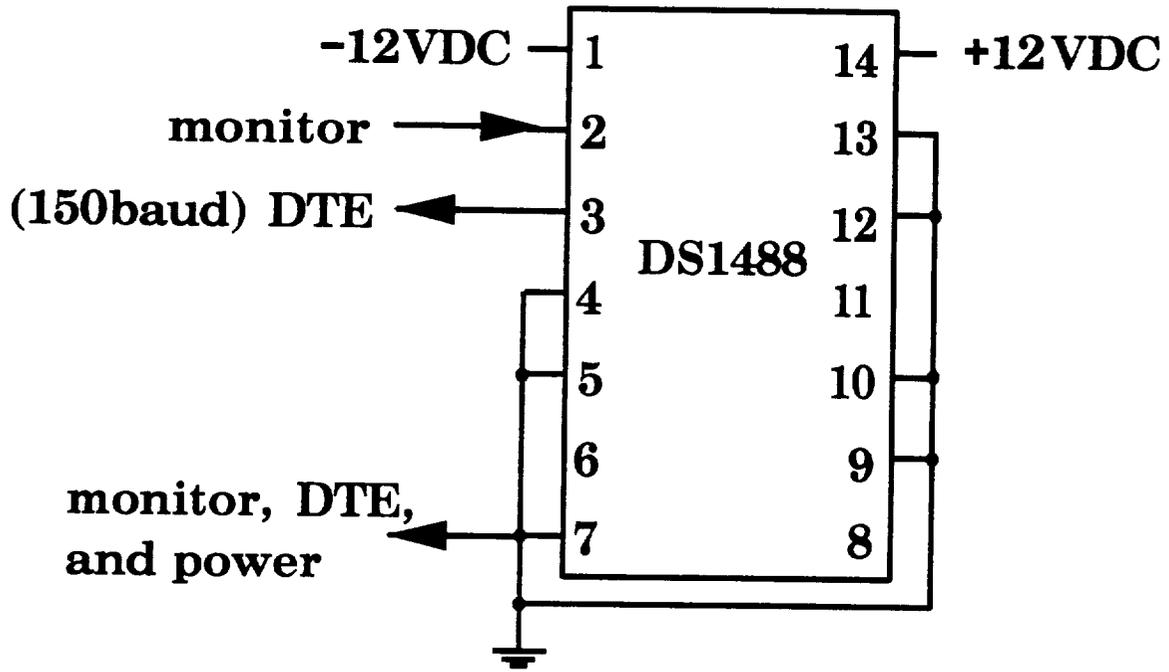


Figure 5a. Monitor-DTE Interface

done
 count = 00A8
 threshold = increased sensitivity (00C0)
 battery voltage = ED
 (alarm set)

Figure 5b. Sample Diagnostic Output

